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Optical Fiber Transmission System

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SPECIFICATION

1. Title of the Invention: Optical Fiber Transmission System

2. Claims

(1) An optical fiber transmission system in which an optical fiber amplifier based on an optical fiber is provided in an optical transmission line from an optical transmitter to an optical receiver and transmitted signal light entering said optical fiber amplifier is multiplexed with exciting light and optically amplified to reduce transmission loss, the system comprising:

exciting light abnormality detection means, located in said optical fiber amplifier, to monitor the condition of said exciting light and detect an exciting light abnormality according to information obtained by monitoring;

modulation means, located in said optical fiber amplifier, to modulate the intensity of said exciting light according to the result of detection by said exciting light abnormality detection means; and

monitoring means, located in said optical receiver, to demultiplex exciting light from transmitted signal light and decide whether an abnormality exists at the upstream, according to the condition of demultiplexed exciting light.

(2) The optical fiber transmission system as claimed in Claim 1, characterized in that said modulation means modulates the intensity of said exciting light in a range where the gain of said optical fiber amplifier is saturated.

(3) The optical fiber transmission system as claimed in Claim 1, characterized in that said modulation means modulates the intensity of said exciting light with a frequency which is much higher than the frequency band of said transmitted signal light.

(4) The optical fiber transmission system as claimed in Claim 1, characterized in that said optical fiber amplifier has an input abnormality detection means to demultiplex

exciting light from input light and detect an abnormality existing at the upstream according to the condition of the demultiplexed exciting light, and when an abnormality is detected by this means, said exciting light is intensity-modulated.

(5) The optical fiber transmission system as claimed in Claim 1, characterized in that said optical fiber amplifier has an output abnormality detection means to monitor output light and detect an output abnormality according to information obtained by monitoring and when an abnormality is detected by this means, said exciting light is intensity-modulated.

(6) The optical fiber transmission system as claimed in Claim 1, characterized in that:

said optical fiber amplifier has an input abnormality detection means to demultiplex exciting light from input light and detect an abnormality existing at the upstream according to the condition of the demultiplexed exciting light; an output abnormality detection means to monitor output light and detect an output abnormality according to information obtained by monitoring; and modulation control means to selectively change and control the modulation frequency of said modulation means according to abnormality detection information from said input abnormality detection means, output abnormality detection means and exciting light abnormality detection means; and that

said optical receiver has a frequency identifying means to identify the modulation frequency of said demultiplexed exciting light.

3. Detailed Description of the Invention

[Object of the Invention]

[Industrial Field of Utilization]

The present invention relates to an optical fiber transmission system in which an optical fiber amplifier for amplifying an optical signal by an optical fiber is provided in a optical transmission line between an optical transmitter and an optical receiver.

[Prior Art]

In an existing optical fiber transmission system, repeaters are provided at regular intervals in an optical transmission line in order to compensate for transmission loss. In each of these repeaters, transmitted signal light is converted into an electric signal by a photodetector; then the electric signal is amplified by an amplifier and reconverted into an optical signal through a semiconductor laser, LED or the like, then the optical signal is sent to the optical transmission line. Hereinafter, a repeater which involves

optical-electrical and electrical-optical conversion processes is referred to as an "electrical optical repeater."

Recently, research in optical amplifiers which use optical fibers (hereinafter referred to as optical fiber amplifiers) has been in progress and demonstrates that they provide excellent characteristics. Unlike electrical optical repeaters, optical fiber amplifiers do not involve optical-electrical and electrical-optical conversion processes in repeating operation and may be thus considered as all-optical repeaters. The use of optical fiber amplifiers as repeaters contributes to repeater size reduction and power saving.

Fig.6 shows an optical fiber transmission system which uses an optical fiber amplifier. As shown in the figure, there is a signal source 11 on the transmitting side. A signal coming from this signal source 11 is modulated by an optical transmitter 12 to become signal light in the $1.5\ \mu\text{m}$ wavelength band and sent to an optical transmission line 13 as an optical fiber line. Since this optical transmission line 13 does not have an amplifying function, the signal light undergoes transmission loss. The transmission loss in the signal light is compensated for by an optical fiber amplifier 14.

This optical fiber amplifier 14 is composed of an exciting light source, a multiplexer for multiplexing input light with exciting light and an Er-doped optical fiber, an optical fiber with a core doped with erbium. The latest type of optical fiber amplifier provides excellent characteristics. Fig.7 shows the internal structure of the abovementioned optical fiber amplifier 14. As shown in Fig.7, signal light coming through an input port 141 from the optical transmission line 13 enters a multiplexer 142. In the multiplexer 142, incoming signal light is multiplexed with exciting light (for example, light in the $1.48\ \mu\text{m}$ band) from the exciting light source 143. The multiplexed light is sent to an Er-doped optical fiber 144. This optical fiber 144 has an amplifying function. The signal light amplified by the optical fiber 144 and the remaining exciting light are sent through an output port 145 to an optical transmission line 15.

In this way, the signal light whose transmission loss has been compensated for by the optical fiber amplifier 14 again enters the optical transmission line 15 which has no amplifying function, and then goes to an optical receiver 16 located a certain distance away. Fig.8 shows the structure of an input portion of the optical receiver 16. As shown in Fig.8, the multiplexed light coming through an input port 161 from the optical transmission line 15 once enters a bandpass filter 162. This bandpass filter 162 is intended to remove the exciting light in the $1.48\ \mu\text{m}$ band from the multiplexed light. After removal of the exciting light, the signal light is sent to a light receiving device 163

where it is converted into an electric signal as a reception signal. An optical fiber transmission system is thus constituted.

As compared with an electrical optical repeater, an all-optical repeater which uses an optical fiber amplifier as mentioned above has a problem to be solved from the viewpoints of operation, management and maintenance because of its special feature that optical-electrical conversion and electrical-optical conversion processes are not involved.

Generally, in an electrical optical repeater, the condition of a signal which has been subjected to optical-electrical conversion and transmitted is monitored and processed by an electrical means and if an abnormality is found, information indicating the abnormality is added to the electrical signal; then it is reconverted into an optical signal which is then sent to an optical fiber. In this constitution, an abnormality existing at the upstream of the transmission system can be detected at its downstream, which makes operation, monitoring and maintenance of the transmission system easy.

On the other hand, an all-optical repeater has neither effective means to monitor the condition of the signal and deal with it nor effective means to detect an abnormality and add information on the existence of the abnormality, so it is impossible for an abnormality existing at the upstream to be detected at the downstream. This means that in a transmission system using an all-optical repeater, if it does not have a monitoring line independently from a transmission line which carries a main signal, operation, management and maintenance of the system is difficult.

[Problem to be Solved by the Invention]

As described above, in an optical fiber transmission system which uses a conventional all-optical repeater, a monitoring line independent from a main signal transmission line is needed in order for an abnormality at the upstream to be detected at the downstream and it is not easy to perform operation, management and maintenance of the system.

The present invention has been made to solve the above problem and its primary object is to provide an optical fiber transmission system which allows an abnormality existing at the upstream to be easily detected at the downstream without a special monitoring line, and thus makes operation, management and maintenance of the system easy.

[Constitution of the Invention]

[Means for Solving the Problems]

In order to achieve the above object, the present invention provides an optical fiber transmission system in which an optical fiber amplifier based on an optical fiber is provided in an optical transmission line from an optical transmitter to an optical receiver and transmitted signal light entering the optical fiber amplifier is multiplexed with exciting light and optically amplified to reduce transmission loss. The system comprises: exciting light abnormality detection means, located in the optical fiber amplifier, to monitor the condition of the exciting light and detect an exciting light abnormality according to information obtained by monitoring; modulation means, located in the optical fiber amplifier, to modulate the intensity of the exciting light according to the result of detection by the exciting light abnormality detection means; and monitoring means, located in the optical receiver, to demultiplex exciting light from transmitted signal light and decide whether an abnormality exists at the upstream, according to the condition of the demultiplexed exciting light.

[Function]

In the above optical fiber transmission system, the condition of the transmission system is continuously monitored for an abnormality and if an abnormality is detected, the intensity of exciting light is modulated and the modulated exciting light is multiplexed with the signal light; in the optical receiver, the exciting light is removed (demultiplexed) from the transmitted optical signal and the condition of the resulting signal is checked to see if there is an abnormality at the upstream.

[Preferred Embodiments]

Next, preferred embodiments of the present invention will be described referring to Figs. 1 to 4.

Fig.1 shows a first embodiment of the invention. In Fig.1, the same components as those shown in Figs. 5 and 6 are designated by the same reference numerals, and a description given here focuses on other components.

Signal light coming from the optical transmission line 13 enters an optical fiber amplifier 21. The optical fiber amplifier 21 sends the signal light from the optical transmission line 13 connected with an input port 211 to a multiplexer 212 where the signal light is multiplexed with exciting light from an exciting light source 213 and optically amplified with an Er-doped optical fiber 214 before being sent to the optical transmission line 15.

The optical fiber amplifier 21 further comprises a monitor circuit 216 for monitoring output of the exciting light source 213 for an abnormality and a modulator

217 for modulating the optical output intensity of the exciting light source 16. If the output intensity of the exciting light source 213 is not within a prescribed range, the monitor circuit 216 detects it and generates an abnormality detection signal; upon reception of this abnormality detection signal, the modulator 217 modulates the optical output intensity of the exciting light source 213 with a given frequency.

The output light from the optical fiber amplifier 21 goes through the optical transmission line 15 to an optical receiver 22. This optical receiver 22 receives the light coming through an input port 221 from the optical transmission line 15. This incoming light is made incident on a demultiplexer 222. The demultiplexer 222 sends the light in the signal light wavelength band to a light receiving device 223 for receiving signals and the remaining light (including exciting light) to a light receiving device 224 for monitoring the transmission line. The signal received by the light receiving device 223 for receiving signals is sent to a reception circuit and demodulated. The signal received by the light receiving device 224 for monitoring the transmission line is sent to an abnormality detector 225 where an abnormality in the optical fiber amplifier 21 is detected by checking if the intensity of exciting light has been modulated or not.

Referring to Fig.2, the abnormality detection sequence in the above constitution is explained below.

Fig.2 is a characteristic graph for the optical fiber amplifier 21, where the horizontal axis represents the intensity of exciting light and the vertical axis represents the gain of the optical fiber amplifier. As can be understood from the graph, in the lower exciting light intensity range (1), as the exciting light intensity goes up, the gain of the optical fiber amplifier increases, but after the exciting light intensity reaches a certain level (namely, in the higher exciting light intensity range (2)), the gain of the optical fiber amplifier remains unchanged (saturation state) even when the exciting light intensity goes up.

When the exciting light in the intensity range (1) is modulated, the optical fiber amplifier gain for the signal light is intensity-modulated and as a consequence, the signal light is also intensity-modulated, which unfavorably affects the demodulation on the receiving side. For example, if the transmitted signal light is a PCM signal, a deterioration in reception signal eye opening and an increase in jitter may result; if the transmitted signal light is an FM signal, AM-PM conversion may result, causing a deterioration in the reception signal's S/N ratio. On the other hand, when the exciting light in the intensity range (2) is modulated, the optical fiber amplifier gain for the signal light remains unchanged and as a consequence, the signal light does not newly undergo intensity modulation and there is no unfavorable influence on the

demodulation on the receiving side.

For the above reason, in this embodiment, the exciting light source 213 in the optical fiber amplifier 21 is driven with an intensity above a prescribed level and its output is monitored by the monitor circuit 216 and in the case of occurrence of an abnormality, the modulator 217 modulates the exciting light source 213 to make its output intensity above the predetermined level so that the abnormality in the optical fiber amplifier 21 is detected by the optical receiver 22. In this constitution, only the exciting light component of the multiplexed light sent to the optical receiver 22 is modulated. In the optical receiver 22, the exciting light component separated by the demultiplexer 222 is sent through the monitoring light receiving device 224 to the abnormality detector 225 which detects if the exciting light has been modulated. Thus, an abnormality in the optical fiber amplifier 21 can be detected without a special monitoring line.

In the above embodiment, upon occurrence of an abnormality, the exciting light source 213 is modulated. An alternative approach which is contrary to this may be that the exciting light source 213 is modulated in a normal condition and the modulation is stopped upon occurrence of an abnormality. This approach produces the same effects as above.

Next, another preferred embodiment of the present invention will be explained referring to Fig.3. The same components as those shown in Fig.1 are designated by the same reference numerals and their descriptions are omitted here.

This embodiment makes it possible to not only detect or monitor for an abnormality in the exciting light in the optical fiber amplifier 21 but also detect or monitor for an exciting light abnormality in a device upstream of the optical fiber amplifier 21 or an abnormality other than exciting light abnormality in the optical fiber amplifier 21 (for example, an abnormality in the optical fiber 214).

As shown in Fig.2, the transmitted signal light entering through the input port 211 is partially sent through a demultiplexer 218 to a monitoring light receiving device 219. The light receiving device 219 detects the level of the transmitted signal light and sends the detection signal to a modulation control circuit 2110. The modulation control circuit 2110 controls the modulation frequency of a modulator 217 depending on how it judges the situation. Specifically, if the level of the transmitted signal light coming from the light receiving device 219 is not within a prescribed range, it decides that an abnormality has occurred upstream of the optical fiber amplifier 21 (for example, in the transmission line or optical transmitter); and if the detection signal comes from a monitor circuit 216, it decides that the output light of the exciting light source 213 of the

optical fiber amplifier 21 is abnormal. In the modulator 217, the modulation frequency should be variable.

In the above constitution, the modulation control circuit 2110 works as follows.

First, it checks the output level of the light receiving device 219 and if it detects a decline in the output level, it decides that an abnormality has occurred in the optical transmitter 12 (see Fig.1) or in the optical transmission line up to the optical fiber amplifier 21. Furthermore, if it detects a decline in the output level of the monitor circuit 216, it decides that an abnormality has occurred in the exciting light source 213. It selects the modulation frequency depending on the decision it has made for each situation to control operation of the modulator 217. Here, the selectable modulation frequency range should match the optical fiber amplifier gain saturation range.

In the above constitution, since exciting light is modulated in a manner to suit the type of abnormality without affecting the signal light and sent to the optical receiver, the optical receiver can know the location of abnormality by checking the modulation frequency of the separated exciting light. This means that an abnormality existing at the upstream can be easily detected at the downstream without the use of a special monitoring line and thus operation, management and maintenance of the system are easy.

Referring to Fig.3, the output level of the Er-doped optical fiber 214 is detected by the light receiving device 2112 after demultiplexing by the demultiplexer 2111 and the result of detection is sent to the modulation control circuit 2110, and if the detected output level is below a prescribed level, it is decided that there is an abnormality in the optical fiber amplifier and exciting light is intensity-modulated with a specific frequency by the modulator 213, so that the optical receiver is notified of the output abnormality.

All the abovementioned embodiments assume that one optical fiber amplifier is provided in an optical transmission line. A case of using plural optical amplifiers in an optical transmission line is explained next.

In this case, if the same type of optical fiber amplifier as the above one is used, when a preceding optical fiber amplifier has modulated the exciting light component and an abnormality occurs in the present optical amplifier, the exciting light is intensity-modulated with the same modulation frequency and therefore the optical receiver cannot identify which optical fiber amplifier is abnormal.

Fig.4 shows an optical fiber amplifier as an embodiment of the invention which enables the optical receiver to identify which optical fiber amplifier is abnormal when plural optical fiber amplifiers are used. In Fig.4, the same components as those shown

in Fig.1 are designated by the same reference numerals and their descriptions are omitted here.

This embodiment is different from the embodiment shown in Fig.3 in that the demultiplexer 218 (Fig.3) is replaced by a demultiplexer 2181. The transmitted light entering through the input port 211 is divided by the demultiplexer 2181 into a signal light component and a remaining light component and the signal light component and the remaining light component are respectively sent to the multiplexer 212 and the light receiving device 219 for monitoring the transmission line. If exciting light has been modulated in a preceding optical fiber amplifier, the detection signal obtained by the light receiving device 219 should have the same frequency as that of the modulated exciting light. The detection signal from the light receiving device 219 and the exciting light abnormality detection signal of the monitor circuit 216 are sent to the modulation control circuit 2110.

When the modulation control circuit 2110 receives a detection signal from the light receiving device 219, it decides that there is an abnormality in the preceding optical fiber amplifier; or if it receives a detection signal from the monitor circuit 216, it decides that the output light from the exciting light source 213 in the present optical fiber amplifier 21 is abnormal. Thus it controls the modulation frequency of the modulator 217 depending on how it judges the situation. In this case, the modulation frequency of the modulator 217 should be variable.

In the above constitution, the modulation control circuit 2110 works as follows like the embodiment shown in Fig.3.

First, it checks the output level of the light receiving device 219 and if it detects a decline in the output level, it decides that an abnormality has occurred in the output portion of the preceding optical fiber amplifier or the optical transmission line up to the present optical fiber amplifier 21. If it finds a signal with a specific frequency in the output of the light receiving device 219, it decides that an abnormality has occurred in the preceding optical fiber amplifier. Furthermore, if it detects a decline in the output level of the monitor circuit 216, it decides that an abnormality has occurred in the exciting light source 213. It selects the modulation frequency depending on the decision it has made for each situation to control operation of the modulator 217. Here, the selectable modulation frequency range should match the optical fiber amplifier gain saturation range.

In the above constitution, since exciting light is modulated in a manner to suit the type of abnormality without affecting the signal light and sent to the optical receiver, the optical receiver can know the location of abnormality by checking the modulation

frequency of the separated exciting light. This means that an abnormality existing at the upstream can be easily detected at the downstream without the use of a special monitoring line and thus operation, management and maintenance of the system are easy.

Like the embodiment shown in Fig.3, the output level of the Er-doped optical fiber 214 is detected by the light receiving device 2112 after demultiplexing by the demultiplexer 2111 and the result of detection is sent to the modulation control circuit 2110, and if the detected output level is below a prescribed level, it is decided that there is an abnormality in the optical fiber amplifier and the intensity of exciting light is modulated with a specific frequency by the modulator 213, so that the optical receiver is notified of the output abnormality.

In the above embodiments, the gain saturation of the optical fiber amplifier is used for intensity modulation of exciting light. Alternatively, the characteristic of gain response may be used for the same purpose. This approach changes the intensity of exciting light in the range where the gain of the optical fiber amplifier cannot follow; the intensity of light which excites the optical fiber amplifier is modulated with a high frequency so that information for operation, monitoring and maintenance of the transmission system including abnormality information can be transmitted to the downstream of the transmission system without causing an unfavorable influence on the signal light.

In this approach, when the exciting light source is modulated, the gain response of the optical fiber amplifier depends on the material of the optical fiber amplifier. In case of a quartz optical fiber amplifier doped with Er, in the 1.5 μm wavelength band where the gain can be large, the gain response cannot follow exciting light intensity modulation with frequencies of several kilohertz or more. Therefore, if the exciting light is intensity-modulated, for example, with a signal having a frequency component of several kilohertz, the gain of the optical fiber amplifier may be considered to remain unchanged over time. Contrariwise, if exciting light should be intensity-modulated with a signal of 10 hertz or so, the gain of the optical fiber amplifier would follow the change in the exciting light and the signal light would also be intensity-modulated, which would unfavorably affect the demodulation on the receiving side.

Fig.5(a) shows an unmodulated signal light pulse train. When this type of signal light is multiplexed with exciting light of 10 hertz or so, the resulting pulse train is as shown in Fig.5(b); here the pulse amplitude is not uniform, which will unfavorably affect the demodulation.

For the above reason, when the exciting light source is intensity-modulated at a

rate at which the gain of the optical fiber amplifier cannot response, only the wavelength of the exciting light can be changed without influencing the signal light. Therefore, this modulation means can also be used to give such information as optical fiber amplifier abnormality information to the downstream.

All the above embodiments have been described in connection with notification of an abnormality in the optical fiber amplifier to the downstream. However, if an optical transmitter is configured in the same way as above, it is possible to notify the downstream of a transmission problem in the optical transmitter. Also, the modulation means may be based on either the gain saturation or gain response of the optical fiber amplifier, or may be based on both to improve the reliability.

Furthermore, when the optical transmission line is a long distance one and an optical receiver is remotely located and it is more convenient for an optical amplifier located midway to monitor for an abnormality in various devices, a monitoring means to detect an abnormality may be provided in the optical fiber amplifier instead of in the optical receiver.

The invention may be embodied in any other forms without departing from the spirit and scope of the invention.

[Effects of the Invention]

As discussed so far, according to the present invention, it is possible to provide an optical fiber transmission system which allows an abnormality existing at the upstream to be easily detected at the downstream without a special monitoring line, and thus makes operation, management and maintenance of the system easy.

4. Brief Description of the Drawings

Fig.1 is a block diagram showing an optical fiber transmission system according to an embodiment of the present invention; Fig.2 is a characteristic graph for the explanation of a modulation means in the embodiment shown in Fig.1; Fig.3 and Fig.4 are block diagrams showing other embodiments of the invention; Figs.5(a) and (b) are waveform charts for the explanation of a modulation means in the embodiment shown in Fig.4; Fig.6 is a block diagram showing the basic configuration of the conventional optical fiber transmission system; Fig.8 is a block diagram showing the basic structure of an optical fiber amplifier in a system shown in Fig.7; and Fig.7 is a block diagram showing the structure of the input portion of an optical receiver in the system shown in Fig.6.

11...Signal source; 12...Optical transmitter; 13...Optical transmission line; 14, 21...Optical fiber amplifier; 15...Optical transmission line; 14, 21...Optical fiber amplifier; 15...Optical transmission line; 16, 21...Optical receiver; 141, 211...Input port; 142, 212...Multiplexer; 143, 213...Exciting light source; 144, 214...Er-doped optical fiber; 145, 215...Output port; 216...Monitor circuit; 217...Modulator; 218...Demultiplexer; 219...Light receiving device for monitoring the transmission line; 2110...Modulation control circuit; 2111...Demultiplexer; 2112...Light receiving device; 2181...Demultiplexer

Fig.1

12	光送信器	Optical transmitter
11	信号源	Signal source
212	光合波器	Multiplexer
213	励起光源	Exciting light source
216	モニタ回路	Monitor circuit
217	変調器	Modulator
222	光分波器	demultiplexer
223	受光素子	light receiving device
224	受光素子	light receiving device
225	異常検出時	Abnormality detector

Fig.2

光信号利得	Optical signal gain
励起強度	Exciting light intensity

Fig.3

	伝送信号光	Transmitted signal light
	合波光	Multiplexed light
218	光分岐器	Demultiplexer
219	受光素子	Light receiving device
212	光合波器	Multiplexer
213	励起光源	Exciting light source
216	モニタ回路	Monitor circuit
217	変調器	Modulator
2110	制御回路	Modulation control circuit
2112	受光素子	Light receiving device

Fig.4

	合波光	Multiplexed light
	合波光	Multiplexed light
218	光分岐器	Demultiplexer
219	受光素子	Light receiving device
212	光合波器	Multiplexer
213	励起光源	Exciting light source
216	モニタ回路	Monitor circuit
217	変調器	Modulator
2110	制御回路	Modulation control circuit
2112	受光素子	Light receiving device

Fig.6

12	光送信器	Optical transmitter
11	信号源	Signal source
14	光ファイバ増幅器	Optical fiber amplifier
16	光受信器	Optical receiver

Fig.7

	信号光	Signal light
	合波光	Multiplexed light
142	光合波器	Multiplexer
143	励起光源	Exciting light source

Fig.8

	合波光	Multiplexed light
163	受光素子	light receiving device
	受信信号	Reception signal